Magnetic Flux Shielding for the Precision Muon g-2 Storage Ring Superconducting Inflector [1]

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Abstract

The muon g-2 experiment (E821)[1] at the AGS requires a precision in the magnetic field over muon orbit at the level of 0.1 ppm. Injection is done with a superconducting inflector involving a double cosine theta winding approximately cancels its fringe field. Nevertheless its residual field would effect the homogeneity of the storage ring magnetic field. A method of using a superconducting sheet surrounding the inflector to further reduce the fringe field is being investigated. The experimental program to explore this technique is described and some test results are presented.

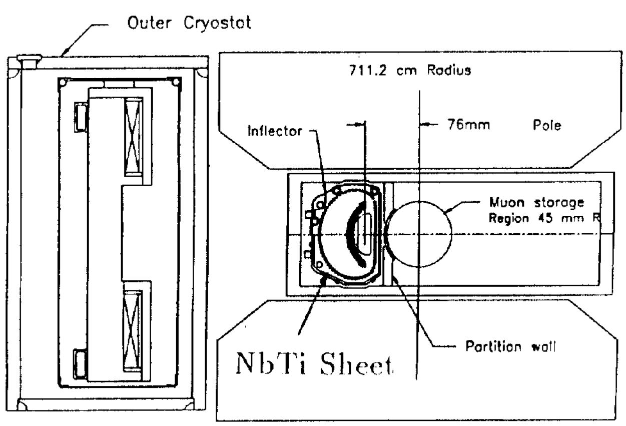

Figure 1: The inflector for the muon storage ring

I. INTRODUCTION

The goal of BNL AGS E821[1] is a measurement of a_μ ($a_\mu = (g-2)/2$) to 0.35 ppm, a factor of 20 improvement over the CERN experiment which achieved 7.2 ppm in 1977.[2] Improvements include much higher proton beam intensity at the AGS due to the booster, and a superferric storage ring which is to be homogeneous over the storage region to 1 ppm and effective magnetic field average around the ring known to 0.1 ppm. At the ring entrance, differing from the coaxial pulsed device in CERN, a superconducting DC inflector was proposed, which locally cancels the field of the main storage ring magnet, so that the beam enters as close as possible and about tangentially to the equilibrium orbit of the ring. The design of the inflector was based on the truncated double cosine principle which minimizes the fringe field by the cancellation of current distributions.[3] In the physical realization, the idea surface current distributions must be replaced by SC windings (Fig.1), hence the cancellation will not be complete due to the discretization and manufacture tolerance. A fringe field at the order of a few ppm over the storage region is estimated. Since this fringe field is a very rapidly varying function of position, it is quite difficult to correct it by using the conventional iron compensation method. In order to eliminate this residual a superconducting sheet will be used to create a opposite multipole currents.

II. PRINCIPLE

When a superconducting surface surrounds a magnetic device, currents are induced in the surface which oppose the changes in magnetic field and effectively reduce the field outside the shield to zero. This supercurrent acts very much like the eddy current described by Faraday's Law of induction and Lenz's Law, except they do not decay. Such shielding is effective up to the critical current density of the material used and requires that no discontinuities exist in the surface where currents must flow to produce the desired field distribution.

III. CONCEPTUAL DESIGN

Unlike most applications[4] (in which the aim is to shield relatively large fields), the residual fringe field of the g-2 inflector is fairly low. This suggests the possibility of using a plain NbTi sheet containing no stablizing normal metal as a relatively unsophisticated shield. The ideal location of the SC sheet is on the outer surface of the inflector housing (Fig.1) where the temperature will remain at 4.6 K as long as the inflector is in operation. The magnitude of the field on this surface is estimated at several hundred gauss.

The inflector must stay above the transition temperature when the storage ring magnet is energized, so that the flux of the main magnetic field can penetrate the SC sheet which is in the normal state. After the main field reaches

[1] Work performed under the auspices of the U.S. Dept. of Energy.

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its stable value (1.45 T), the inflector together with the shield can be cooled to liquid helium temperature. As the current of the inflector increases, dB/dt induces supercurrents in the sheet, which keep the fringe flux from entering the interior of the sheet.

IV. MATERIAL EVALUATION

Magnetization measurements can be used to determine the critical current density of superconductors in sheet form.

A piece of Nb-46.5w/oTi sheet, 0.5 mm thick, was provided by Teledye Wah Chang. Figure 2 shows the critical current density J_c as a function of magnetic field at 4.2 K, measured by BNL Materials Science Division. While this current density is very low compared modern multifilamentary composites, it is high enough to provide significant shielding at low field levels.

V. SHIELDING TEST

In order to examine the shielding capabilities of this sheet before the completion of the inflector, it was tested in the RHIC Magnet Division, using an existing superconducting SSC sextupole coil to simulate the inflector. Figure 3 shows the experiment arrangement. The NbTi sheet surrounds a superconducting sextupole magnet and is equipped with a heater made from stainless steel ribbon, which controls the temperature of the shield. Two Hall probes H_1 and H_2 were used for monitoring the magnetic flux densities inside and outside of the flux shield. They are situated at position where the flux lines are perpendicular to the shield surface. Figure 4 shows the field seen by the probes, as a function of the sextupole current. The shield was capable of excluding flux from the outer region upto the maximum current of the sextupole coil (256 A) where the field at the sheet surface should be about 1250 gauss. With the sextupole current set at 100 amps, probe H_1 was moved along the total length of the coil with

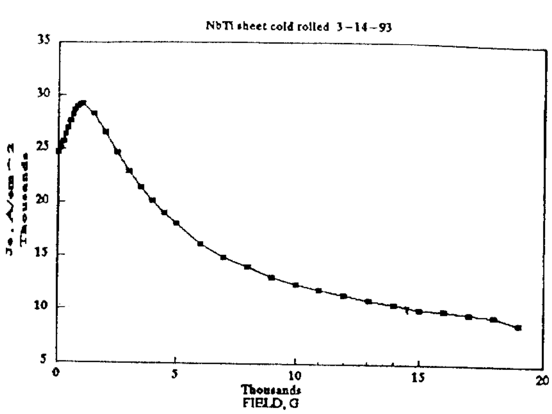

Figure 2: The critical current density of the NbTi sheet deduced from magnetization measurements

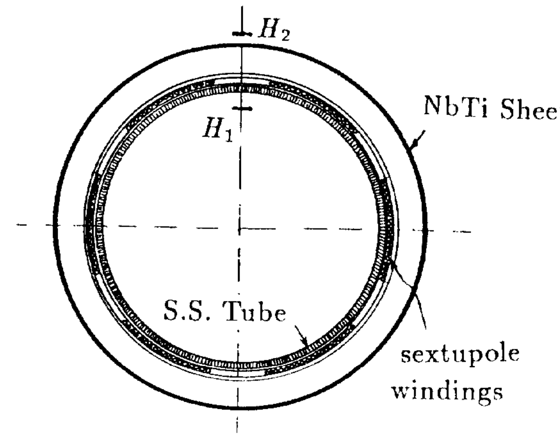

Figure 3: The experiment arrangement used to test the shielding properties of the 0.5mm NbTi sheet.

the shield in both the superconducting and normal states. The results are shown in Fig.5. The sextupole is somewhat longer than the flux shield and is positioned so that one end is not shielded. The transition from the the shielded to the unshielded region occurs smoothly despite the sudden change in the local conditions.

In order to observe some flux penetration, one has to increase the temperature of the sheet by adjusting the power of the heater. This is illustrated in Fig.6 where the maximum current density induced in the NbTi sheet is plotted against temperature. The current density was computed from the flux change inside the sextupole and the temperature estimated from the heater power input. In the temperature range between 4.2 K and 6 K the flux that can be shielded is erratic indicating a lack of stability of the higher current densities in this simple shield.

VI. CONCLUSION

The material evaluation and shielding test verified the feasibility of using superconducting material to eliminate the inflector fringe field. Further tests are planned using

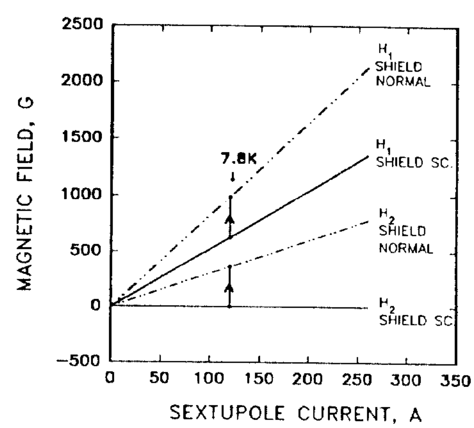

Figure 4: The field at Hall probes 1 and 2 as a function of sextupole current with the flux shield in the superconducting and normal state.

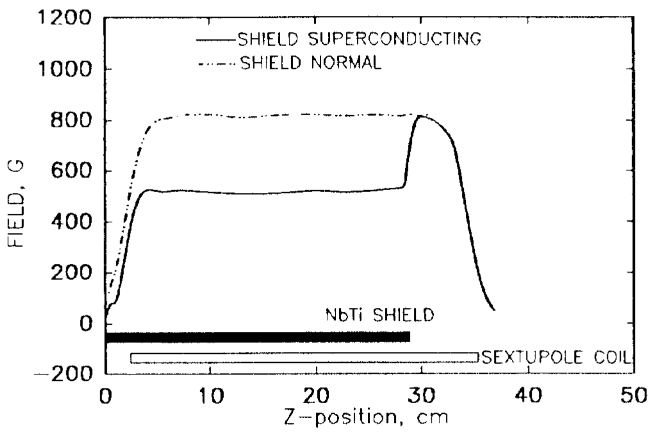

Figure 5: The field distribution along the length of the sextupole at 100 amps with the flux shield in the superconducting and normal state.

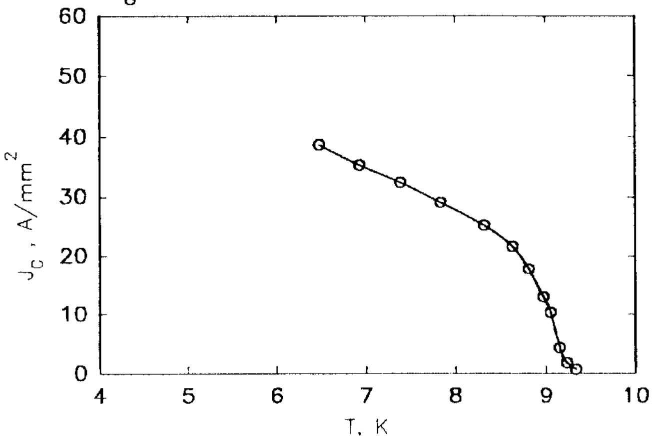

Figure 6: The critical current induced in the superconducting shield as a function of temperature

higher J_c stabilized NbTi sheet[5] on an inflector prototype made by Japan KEK. These tests will be in a background field of 1.45 T to simulate more accurately the actual conditions the inflector will experience in the storage ring.

VII. ACKNOWLEDGEMENT

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VIII. REFERENCES

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